(12) UK Patent Application (19) GB (11) 2 034 417 A

(21) Application No 7937015
(22) Date of filing 25 Oct 1979
(30) Priority data
(31) 53/132041
(32) 25 Oct 1978
(33) Japan (JP)
(43) Application published
4 Jun 1980
(51) INT CL³
F16C 33/32
C23C 13/02
(52) Domestic classification
F2A 114 150 174 5B7
D54
C7F 1A 1V1 2H 2L 2U 2Y
4F 4G 4K 6F1
(56) Documents cited
GB 1358233
GB 931485
GB 565640
GB 510404
(58) Field of search
C7F F2A
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(54) **Improvements in or relating to anti-friction bearings**

(57) In an anti-friction bearing, metallic components to be subjected to rolling friction or sliding friction, such as rolling elements 1, are coated with a multiplicity of metal layers 2 by ion plating. The outermost layer 23 is made of soft metal (e.g. Au or Ag) with a lubricating property. The solid solubility of the metal of each intermediate layer 21, 22 (e.g. Ni and Cu respectively) in each adjacent metal is higher than the solid solubility of the soft metal in the metal material of the element 1. Such a bearing may be used in a vacuum and has an increased working life.

FIG.2

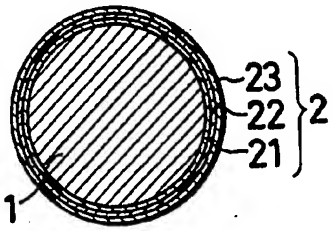

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FIG.1

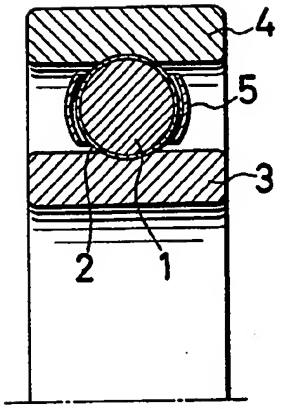


FIG.2

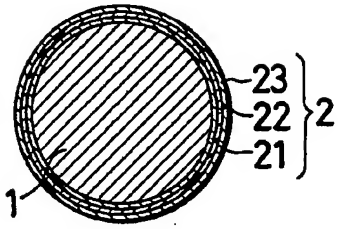


FIG.3

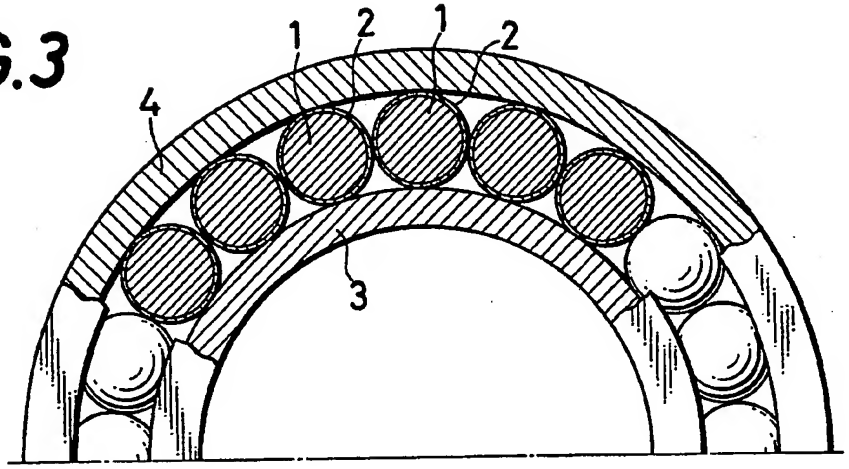
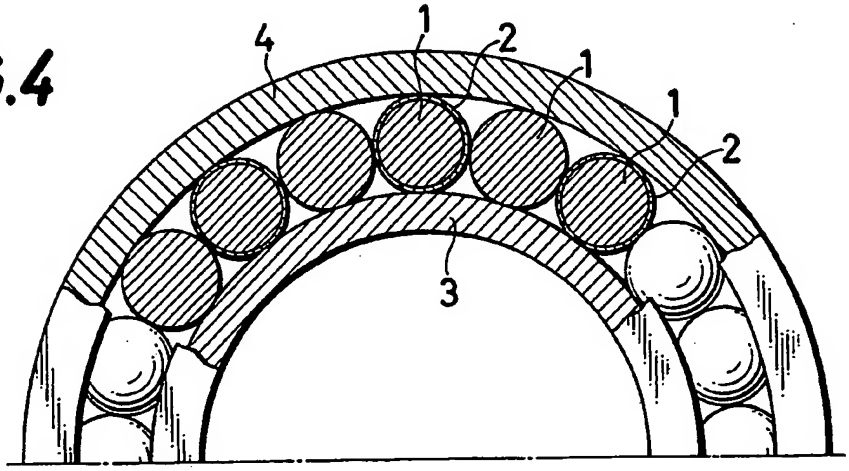


FIG.4



SPECIFICATION

Improvements in or relating to anti-friction bearings

The present invention relates to anti-friction bearings which may be used in a vacuum, for example, in rotating X-ray tube anode assemblies, vacuum evaporation apparatuses and like vacuum apparatus or in devices designed for travel in space.

Bearings for use in a vacuum involve difficulty in lubrication with oil or grease, so that known bearing components, such as rolling elements, are coated with a solid layer of a metal with lubricating properties, molybdenum disulfide or like lubricant for lubricating the surface to be subjected to rolling friction or sliding friction. Generally such metal coatings are formed by the usual ion plating method as disclosed, for example, in Published Unexamined Japanese Patent Application No. 19840/1977.

However, the coatings formed by the conventional ion plating method have the drawbacks of being low in adhesive strength and therefore liable to separation in a short period of time during the operation of the bearing, thus giving a very short life to the bearing.

According to the invention, there is provided an anti-friction bearing comprising metal components to be subjected to rolling friction or sliding friction, at least some rolling elements included in the metal components being coated with at least one intermediate metal layer by ion plating, the intermediate layer being coated by ion plating with an outermost layer of a soft metal with lubricating property, the solid solubility of the metal of the intermediate layer in each metal adjacent thereto being higher than the solid solubility of the soft metal in the metal material of the rolling metal. It is thus possible to provide an anti-friction bearing which is serviceable for a prolonged period of time and in which, of the metal components thereof to be subjected to rolling friction or sliding friction, at least the rolling elements are each coated with a layer of a soft metal with lubricating property, the soft metal layer being formed by an ion plating method and having high adhesive strength.

The invention will be further described, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a view in vertical section showing an embodiment of the invention;

Fig. 2 is an enlarged sectional view showing a rolling element of Fig. 1; and

Figs. 3 and 4 are front views partly broken away and showing other embodiments of the invention.

Figs. 1 to 4 show preferred embodiments of this invention.

Fig. 1 shows a ball 1 serving as a rolling element, a composite coating 2 covering the surface of the ball 1, an inner ring 3 providing a raceway, an outer ring 4 providing another raceway, and a cage 5 for retaining the ball 1.

As schematically shown in Fig. 2, the composite coating 2 comprises metal layers 21 and 22 formed as intermediate layers over the surface of the ball 1 by ion plating and an outermost layer 23 made of a soft metal with lubricating properties and formed over the layer 22 by ion plating. The solid solubility of the metal of each intermediate layer in each metal adjacent thereto is higher than the solid solubility of the soft metal material of the ball 1.

When the uppermost layer 23 is to be made, for example, from gold or silver which is known as a soft metal having a lubricating property, the ball 1 is cleaned and then ion-plated with nickel and thereafter with copper to form the intermediate layers 21 and 22, and the copper layer 22 is subsequently ion-plated with gold or silver to form the outermost layer. The solid solubility of nickel or copper of each intermediate layer in each metal adjacent thereto is higher than the solid solubility of gold or silver in the metal material of the ball 1.

Gold, silver or like soft metal generally known to have a lubricating property has a low solid solubility in iron alloys used for bearing components, such as rolling elements, raceway rings and cages, as listed in Table 1, so that even when such iron alloy material is ion-plated directly with the soft metal, the resulting coating has low adhesive strength and is therefore prone to separation in a short period of time during the rotation of the bearing.

The solid solubilities of metals in other metals listed in Table 1 are those given in Dr. Phil. Max Hansen, "CONSTITUTION OF BINARY ALLOYS" (1958) and expressed in atomic percent (at. %).

Table 1

Combination of metals	*Solubility (at. %)*
Silver in iron	0-0.52
Silver in copper	0.06-4.9
Copper in nickel	100
Nickel in iron	7-9
Gold in iron	1.3-1.5
Gold in copper	20
Silver in nickel	1
Gold in nickel	2

In ion plating, the metal material to be plated and the plating metal undergo direct atom-to-atom reaction in an inert gas atmosphere, so that the adhesive strength of the plating layer is more dependent on the solid solubility of one metal in the other metal than is the case with other plating methods. It is further noted that gold or silver, a soft metal with a lubricating property, has a low solid solubility in iron alloys which are widely used as materials for bearing components. In view of these properties, at least one intermediate metal layer is provided between the material to be plated, namely a bearing component, and an outermost plating layer oif a metal having a good lubricating property although possessing a low solid solubility in the metal to be plated, the metal of the intermediate layer having a solid solubility in each metal adjacent thereto higher than the solid solubility of the plating metal, whereby the lubricating plating metal can be bonded to the bearing component with enhanced strength. It is thus possible to provide a long-life anti-friction bearing which is useful in special environments involving vacuums, super-low temperatures and high temperatures.

Table 2 shows the results of an experiment con-

ducted with the use of an anti-friction bearing constituting a preferred embodiment of the invention, an anti-friction bearing coated by the conventional ion plating method and an anti-friction bearing having no plated component to test the bearings for service life.

Table 2

Kind of specimen	*Life ratio*
Anti-friction bearing of the invention in which the rolling elements alone are ion-plated with Ni, then with Cu and thereafter with Au	700
Anti-friction bearing with its rolling elements alone ion-plated directly with Au by conventional method	9
Unplated usual anti-friction bearing	1

The type of the bearings used for the experiment and the test conditions are as follows.

Type of bearings:	Ball bearing No. 6000
Test conditions:	
Temperature	room temperature
Pressure	1×10^{-5} torr or lower
Rotation	200 r.p.m.
Thrust load	48 kg

Table 3 shows the results of another experiment conducted with the use of anti-friction bearings constituting a preferred embodiment of the invention with a cage as shown in Figure 1 or without any cage as shown in Figure 3 to test the bearings for service life.

Table 3

Type of bearing Plating	*Cage*	*Life ratio*
With rolling elements only ion-plated with Ni, then with Cu, thereafter with Au	None	60
Do	With cage	120
With rolling elements only ion-plated with Ni, then with Cu, thereafter with Ag	None	200
Do	With cage	250

The type of the bearings used for the experiment and the test conditions are as follows.

Type of bearings: No. 626

Test conditions:

Temperature	room temperature
Pressure	1×10^{-5} torr or lower
Rotation	200 r.p.m.
Thrust load	15 kg

The foregoing results indicate that the anti-friction bearings constituting preferred embodiments of the invention have a much longer life than anti-friction bearings with the rolling elements coated with gold or silver by the conventional ionplating method. With anti-friction bearings coated by the conventional ion plating method, it is known that the cage for retaining the rolling elements acts to wear and separate the coating during the rotation of the bearing, with the result that anti-friction bearings with no cage have a longer life than those having a cage, whereas the test result given in Table 3 reveals that with the anti-friction bearings constituting preferred embodiments of this invention, that having a cage have a longer life than those without any cage, which is contrary to what has heretofore been believed. This is because the coating layer of lubricating soft metal, i.e. gold or silver, is bonded with high strength to the double intermediate layer 21, 22 of nickel and copper formed on the surface of the rolling element, such that the metal of the intermediate layer has a high solid solubility in the metal of each layer adjacent thereto.

As already described, at least the rolling elements of the anti-friction bearing are formed with a composite coating 2 over the surface, because the effective contact surface area involving lubrication is then much larger than when the composite coating 2 is formed on the race or cage and achieves a greatly improved lubricating efficiency. Additionally the coating is easier to form. Especially when the rolling element is a ball as described above, the portion of the ball in contact with the races changes during the rotation of the bearing due to the spinning action of the ball. This enables the entire surface of the ball to serve as an effective contact area, thus affording very high lubricity.

However, the part to be formed with the composite coating 2 is not limited to the rolling element 1, but such a composite coating may be provided similarly over the raceways of the inner and outer rings 3 and 4. Table 4 shows the results of another experiment in which a bearing so coated was tested for serviceability in comparison with other bearings.

Table 4

Kind of specimen	*Life ratio*
Anti-friction bearing constiting a preferred embodiment of the invention with rolling elements ion-plated with Ni, then with Cu, thereafter with Ag	19
Anti-friction bearing constituting a preferred embodiment of the invention with rolling elements and inner and outer rings ion-plated with Ni, then with Cu, thereafter with Ag	18
Unplated usual anti-friction bearing	1

The type of the bearings used for the experiment and the test conditions are as follows.

Type of bearings: Ball bearing No. 727

Test conditions:

Temperature	Room temperature
Pressure	1×10^{-5} torr or lower
Rotation	100 r.p.m.
Thrust load	6 kg
Radial load	4.6 kg

The test results given in Table 4 indicate that the ball bearing in which the inner and outer raceways, like the balls, are coated with a silver layer has nearly the same long life as one in which the rolling elements alone are coated.

Although all the rolling elements 1 of each embodiment described above for supporting the bearing load are formed with the intermediate nickel and copper layers 21 and 22 and the outermost gold or silver layer 23 covering the layer 22, every other ball 1 may be formed with the coating 2 as shown in Figure 4, in the case of bearings of the type including no cage, for example in ball bearings. Table 5 shows that the bearing so coated has a longer life than one in which all the balls 1 have the coating 2.

In this case, the balls 1 having the coating 2 are diametrically larger than the uncoated balls 1 by an amount corresponding to the thickness of the coating 2. The coated balls 1 support the bearing load, while the uncoated balls serve as spacers.

Table 5

Kind of specimen	*Life ratio*
With all balls ion-plated with Ni, then with copper, thereafter with Ag (ball bearing No. 626)	5
With every other ball ion-plated with Ni, then Cu, thereafter with Ag (ball bearing No. 626)	12

Test conditions:

Temperature	Room temperature
Pressure	1×10^{-5} torr or lower
Rotation	3,200 r.p.m.
Thrust load	15 kg

Although the embodiments described above are ball bearings, the invention is also useful for anti-friction bearings of other types, such as cylindrical roller bearings, tapered roller bearings and spherical roller bearings.

In a preferred anti-friction bearing, of the metal components thereof to be subjected to rolling friction or sliding friction, at least every other rolling element 1 is ion-plated with nickel and then with copper to form intermediate nickel and copper layers 21 and 22 and is further ion-coated with gold or silver to form an uppermost layer 23 over the copper layer 22, the solid solubility of the metal of each intermediate layer in each adjacent metal being higher than the solid solubility of gold or silver in the metal material of the rolling element 1. As a result, the gold or silver layer 23 can be fomed over the rolling element 1 with high adhesive strength, with the nickel and copper layers 21 and 22 interposed therebetween, so that the gold or silver layer 23 can be held to the rolling element 1 over a prolonged period of time despite the rotation of the bearing. This gives a greatly prolonged life to the bearing.

Whereas it has been thought that the cage acts to promote the separation of the coating from the rolling element, the cage, if used in an anti-friction bearing constituting a preferred embodiment of this invention, produces no adverse effect on the gold or silver layer 23 but is rather allowed to fully perform its contemplated function, thus eliminating the necessity of forming a groove for the balls and reducing the number of assembly steps needed for fabrication.

Although nickel and copper are used for the intermediate layers 21 and 22 for covering the rolling element 1 with use of gold or silver as a lubricating soft metal for the outermost layer according to the foregoing embodiments, the metals for the intermediate layers and the lubricating metal are not limited to these examples.

While the above embodiments include nickel and copper intermediate layers, the rolling element 1 may be ion-plated with a single intermediate layer, for example, of nickel and further ion-plated with gold or silver. The gold or silver layer can be formed with higher adhesive strength than heretofore possible.

CLAIMS

1. An anti-friction bearing comprising metal components to be subjected to rolling friction or sliding friction, at least some rolling elements included in the metal components being coated with at least one intermediate metal layer by ion plating, the intermediate layer being coated by ion plating with an outermost layer of a soft metal with lubricating property, the solid solubility of the metal of the intermediate layer in each metal adjacent thereto being higher than the solid solubility of the soft metal in the metal material of the rolling metal.

2. An anti-friction bearing as claimed in claim 1, wherein the metal components comprise the rolling elements, a cage, an inner ring and an outer ring.

3. An anti-friction bearing as claimed in claim 1, wherein the metal components comprise the rolling elements, an inner ring and an outer ring.

4. An anti-friction bearing as claimed in any one of the preceding claims, wherein the metal components are made of an iron alloy, the intermediate layer is made of nickel and the outermost layer is made of gold or silver.

5. An anti-friction bearing as claimed in any one of claims 1 to 3, wherein the metal components are made of an iron alloy, and the rolling elements are coated with a lower intermediate layer of nickel and an upper intermediate layer of copper, the outermost layer being made of gold or silver.

6. An anti-friction bearing as claimed in any one of the preceding claims, wherein the rolling elements are balls or rollers.

7. An anti-friction bearing as claimed in claim 3 or in any one of claims 4 to 6 when dependent on claim 3, wherein uncoated rolling elements are arranged alternately with the coated rolling elements.

8. An anti-friction bearing substantially as hereinbefore described with reference to an as illustrated in the accompanying drawings.

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1980.
Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.